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# An external index of egg quality

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AN EXTERNAL INDEX OF EGG QUALITY

by

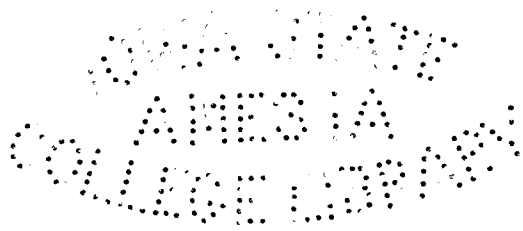
Harold L. Wilcke

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## INTRODUCTION

"Egg quality" is a term which has been discussed for many years from the standpoint of marketing, but the production of quality eggs has not been extensively studied until the past decade. Certain characteristics have been accepted as being representative of egg quality, but there has been little scientific basis for some of them. Egg quality refers to the desirability of the egg for human consumption. The consumer is willing to pay and does pay, a premium for the type of egg that he desires, whether his preference is based upon fact or upon some individual whim. The producer cannot expect to meet the fancies of all the consumers, yet past records prove that by far the greater majority of the purchasers of eggs are quite uniform in their demands within localities and within definite market classes. The production of eggs which would meet the requirements of the buyers would increase tremendously the number of eggs which could be sold as first grade eggs, thereby increasing the revenue to the producer. The significance of this fact may be brought out more clearly by considering the value of the poultry products produced annually, and the percentage of this value that may be attributed to eggs.

In 1934, the total egg production for the United States was 31,006,000,000 eggs, valued at \$433,510,000 (17). The value of the poultry produced on the farms for the same year was \$242,422,000, or a total value of \$675,932,000 for the two major sources of income for commercial poultry. From these figures, it may be seen that eggs accounted for 64.13 percent of the value of the poultry products produced in 1934. In Iowa, where \$47,695,000 worth of poultry and eggs were produced in 1934, eggs accounted for 58.3 percent of the total, or \$27,802,000. These values represent a decline from the peak reached a few years earlier, but the volume represents an increase in production which has been paralleled by few other branches of the livestock industry in recent years.

Coincident with the increase in production, an extensive system of marketing has been developed. The chief objective of the earlier poultry and egg dealers was to attain the maximum volume of business, but as the volume of production has steadily increased, the emphasis has been shifted to quality. Standards and grades have been set up which describe in detail the characteristics of eggs which are considered to be of good quality. These standards are quite widely accepted as the basis for buying and selling eggs. A device known as a "candle", which focuses a strong beam of light upon the egg, partially illuminating the contents, is used in grading eggs. The egg is rotated before the candle with a sharp twirling

motion. The size of the air cell, the rapidity of yolk movement, and the yolk visibility are used as indices of interior quality. Large air cells, rapidly moving and distinctly visible yolks are considered to be indications of age or inferior quality. Yolk movement and yolk shadow are presumed to be affected by the relative amounts of thick and thin albumen. Consequently, much of the research on egg quality has been directed toward the relative amounts of thick and thin (or firm and liquid) albumen in individual eggs. However, it was felt that a study of the entire contents of the egg was desirable. The rotation used in candling seemed to be most nearly approached by that of the torsion pendulum, which has been used in this work.

Two other methods are commonly used in studying egg quality. The yolk index was developed by Sharp and Powell (14). In this procedure, the egg is broken out, and the albumen is removed by means of a pipette. The remaining albumen is removed from the yolk by gently rubbing with a soft, wet cloth. The yolk is then placed on a flat-bottomed petri dish, and after a definite time (usually five minutes) has elapsed, the height and diameter of the yolk are measured. The height divided by the width yields a quotient which is known as the "numerical or yolk index". A large index is indicative of good quality.



The yolk index was evidently not intended to be used in studying the relative amounts of thick and thin albumen in the egg, but Perry (12) found a highly significant positive correlation between yolk index and percent thick albumen.

The other method of studying egg quality was proposed by Holst and Almquist (7). When this method is used, the equipment necessary is a funnel, a graduated cylinder, and a sieve which is four inches in diameter, has a one-half inch raised rim, and a mesh of nine per inch. The yolk is carefully separated from the albumen, which is poured on the sieve. The thin albumen passes through into the graduate, and the thick portion is retained on the sieve. The volume of the thin albumen is determined, and the thick is then added, total volume being obtained by direct readings in the graduate. This method, with minor changes, is quite widely used to separate thick and thin albumen. A slight modification, to increase the accuracy, has been suggested by Knox and Godfrey (8).

There are five obvious disadvantages to these methods of studying the two types of albumen. The first is that there is undoubtedly incomplete separation in many cases, particularly in view of the findings of Almquist and Lorenz (2) who have shown that a certain portion of the thin albumen is enmeshed within the sac-like formation of the thick albumen. Therefore, unless all of this thin albumen is released, it is measured with the thick portion. This has been the case in many

instances. Furthermore, it is conceivable that these methods, in the hands of different operators, might yield varying results, thus rendering results obtained by different experimenters incomparable. Much information may be lost when such is the case.

A second disadvantage to these methods is that the structure of the albumen may be disturbed when the egg is broken out and passed through screens, or pipettes, or both. This was the experience of St. John and Green (16) who found that the plasticity value of thick albumen was proportional to the number of times the sample was passed through a Gooch crucible.

A third serious objection to these methods is that once the egg is broken out it is no longer available for other studies, such as storage studies on the same egg, or for incubation purposes. If one wishes to study the inheritance of the ability of the hen to produce eggs containing high percentages of thick and thin albumen, it would seem desirable to have some measure of the contents of the eggs actually used.

A fourth objection to the screen method of separation is the time required to break the egg and make the separation. This is a slow and laborious task at best.

Finally, with the exception of the technic developed by Van Wagenen and Wilgus (18), no attempt has been made to detect differences in the viscosity of the thick or thin albumen of individual eggs.

In view of these drawbacks to the methods in use, it seemed highly desirable to attempt to develop a method for evaluating quality which would possess the following characteristics:

1. It should be an external measure. This would provide a measure of the egg contents as they existed in the egg, and not after their natural relationships had been destroyed.

2. It should provide a measurement of those qualities which are actually influencing the commercial grading of eggs. It has been assumed that yolk-index and the proportion of thick and thin albumen are the determining factors, but the interrelation of these individual components has not been studied. It would be reasonable to assume that differences in the chalazae might influence the rapidity of yolk movement, and also the density of the shadow which would not be accounted for after the egg had been broken out. Other relationships within the egg may reasonably be postulated as influencing the movement of the contents when the egg is rotated.

A small difference in the yolk shadow or in the rapidity of yolk movement may easily place an egg in a lower commercial grade, resulting in a lower price for that egg. With an annual egg production of approximately 2.6 billion dozens of eggs, it is obviously an economically sound policy to attempt either to change the egg grading standards so as to eliminate any possibility of discrimination against eggs produced in certain

geographical locations; or to produce eggs which will qualify in the higher grades under the present standards. Since the present standards are intended to eliminate aged eggs, and accomplish this objective with a reasonable degree of accuracy, it seems more logical to attempt to produce eggs which will be placed in the higher grades.

3. It should be convenient and rapid.

4. It should provide a measure which can be duplicated readily by other workers.

5. It should be precise. In order for any results to be valuable, they should be capable of duplication within a reasonable degree of accuracy.

If such a method could be found, the study of the effect of nutrition and of breeding on differences in the quality of eggs produced would be greatly enhanced.

The objects of this problem are twofold:

1. To develop an external method for determining an index which may be used as a measure of egg quality and which meets the above qualifications.

2. To utilize this method in a study to determine whether the individual hen produces eggs which consistently have approximately the same index, or whether this index value may be influenced by feeding.

Such a method has been devised in this series of experiments, and it has been used in studying the effects of various

rations and of individual hens upon the index of egg quality obtained. Much work remains to be done in perfecting the equipment used. Nevertheless, it has been demonstrated that it is possible to make external measurements of certain interior characteristics. Some of these problems will be discussed and explained in this manuscript. Other interpretations must await further developments. This appears to be a new, but a promising field, in experimental technic for egg studies, and naturally, many of the ramifications of the problems must be left for further study.

## REVIEW OF LITERATURE

Research on problems concerning egg quality has received a remarkable impetus in the past decade. The development of the "yolk-index" technic by Sharp and Powell (14) and the studies of Holst and Almquist (7) on firm and liquid white have opened a new field of investigation.

These methods of study are of greater significance since it has been shown by Canham (4), Almquist (1) and Pennington, True, Rich, and Kiess (11) that differences in the percentage of thick and thin albumen in eggs cannot be detected by candling. The results of these investigators disprove the theory that yolk shadow and yolk movement are determined by the relative viscosity of the egg albumen, and clearly show that our present egg-grading standards are deficient in this respect. However, Pennington and associates (11) found a progressive decrease in yolk index paralleling the four U. S. Grades (Specials, Extras, Standards, and Trades). These results are somewhat at variance with those of Perry (12), who found a highly significant correlation between yolk index and percentage of thick albumen. However, Pennington and associates did not test the statistical significance of their results. There is also a very small difference in yolk index between Extras

and Standards in the summer eggs. Since the complete data for all of the individual eggs were not published, one can only assume that the parallelism between yolk index and candling grades may be due to chance.

Canham (4) agreed with Holst and Almquist (7) in finding less variation in percent of thick albumen in the eggs from the same hen than in those from different hens, but he reported a maximum variation of 21.5 percent between eggs from the same hen. This is in contrast to a maximum difference of 7 percent reported by Holst and Almquist (7). It is possible that this difference in variability may have been caused by greater variability in certain individual hens, or by collecting eggs over a longer period of time.

Lorenz, Taylor, and Almquist (9) have studied the question of variability in the eggs from the same hen in somewhat greater detail. These investigators segregated a line of females which laid eggs containing a high percentage of firm white, and another line which produced eggs yielding a low percentage of firm white. The percent firm white reported for the high line dropped from  $81.5 \pm 1.19$  to  $65.0 \pm 0.58$  in four generations of inbreeding, but this value was still significantly higher than that for birds selected at random. The percent firm white for the low line was not decreased by the breeding program followed, and there was some segregation of high lines from this low percent firm albumen group. From these results,

the authors concluded that genetic factors control the percent firm white of the eggs laid, at least to some extent.

Knox and Godfrey (8) made a slight modification in the method of Holst and Almquist (7) to improve the accuracy of the determination. They used this method to study the percent thick albumen produced by White Leghorns and Rhode Island Reds. They found that their strains of these two breeds differed in this respect, the Leghorns producing eggs which contained a higher percentage of thick white. Antecedent egg production was not correlated with the percentage of thick white or the amount of thick white.

Information regarding the effect of the ration upon the production of thick albumen, or upon the viscosity of the contents of the egg, appears to be extremely meager. Perry (12) found no regular variation in percent of thick albumen in either fresh or storage eggs which could be attributed to the amount or kind of protein supplement in the ration, but he felt that greater differences in the rations used might have produced such a difference. He also studied the reliability of rapidity of yolk movement as judged before the candle as a basis for the estimation of the amount of thick albumen in the egg. Eggs were divided into three grades of yolk movement, and representative samples from each grade were broken out. The percent of thick albumen was determined for each grade,



but the correlation between rapidity of yolk movement and percent of thick albumen was not significant. It is hoped that it may be possible in the near future to establish the relationship between viscosity as determined by the torsion pendulum and the various quality factors as determined by candling.

Cortese (5) made a study of the viscosity of egg albumen, using pressure upon the Ostwald pipette for his determinations. He found that the temperature exerted a pronounced influence upon the change in viscosity of stored eggs. At ordinary temperatures, the viscosity decreases rapidly in spite of the fact that evaporation would tend to increase the concentration of the colloidal solutions. This change was much slower in eggs stored at lower temperatures, but the curves were very regular in both instances.

It is evident that some progress has been made toward determining the nature of some of the factors underlying the differences in fresh eggs. The results reported in this manuscript add to the evidence already reported.

## EXPERIMENTAL

### Development of the Apparatus

As stated above, one of the weaknesses of the technic for egg quality studies is that they fail to consider variations in the viscosity of the contents of the egg. Accordingly, standard methods of determining viscosity of liquids were surveyed, but for the most part, these methods cannot be used for egg albumen, either because of the structure of the albumen, because of its relatively high surface tension, or because of the amount required. The Doolittle Viscosimeter (6) seemed to offer promise, and it was used for composite samples of thick and of thin albumen. With this instrument, 22 degrees rotation were recorded for thick albumen, 14 degrees for thin albumen, and 11 degrees for distilled water, all at 25 degrees C. However, this method could not be used for the albumen from individual eggs because of the large amount of albumen required for the determination. This apparatus involves the principle of the torsion pendulum, and it was the basis for the idea of the apparatus developed for use in this study.\*

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\*This apparatus was suggested by Doctors Lyle D. Goodhue and R. M. Hixon of the Chemistry Department, in whose laboratory it was developed.

### Description of the Apparatus

After several unsuccessful devices had been constructed, the small frame illustrated in Fig. 1 was designed. This consists of a small frame, which has two parts, a vertical frame, A, made of aluminum, and a horizontal brass collar, J, which is large enough to accomodate an egg. This is suspended between two piano steel wires, B and B', which are attached to steel bars, C and D. These bars are clamped to two ringstands, forming a rigid framework. An arm, E, is fastened to the lower part of the framework to provide for adjustments of the weights, F and G. These weights are for the purpose of adjusting the period, which is the time per swing. It is obtained by dividing the time required for a given number of swings by the number of swings. Such changes are necessary only for experimental purposes. In general, decreasing the period increases the accuracy of the determination up to the point where this increase in accuracy is offset by inability to properly observe the number of swings. After some experimentation, the weights and position of the weights illustrated in Fig. 1 were chosen.

A small mirror, H, is attached to the top of the frame, and a light, L, (in this case, a bulb from an automobile tail light) is focused upon this mirror. Three marks were placed at arbitrary places on the wall, and one of these was used as a zero, or starting point. At the beginning of each series of

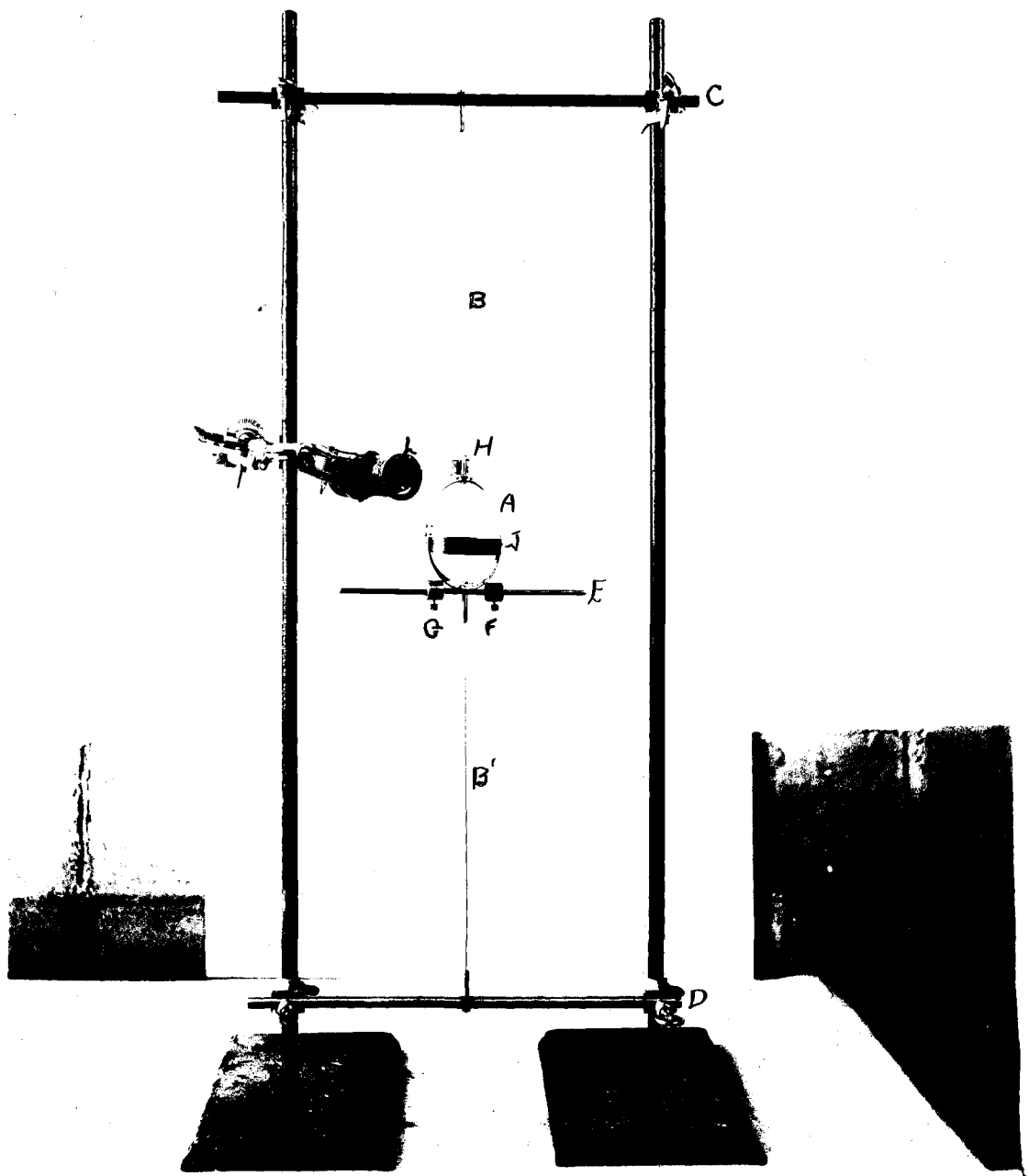


Fig. 1. Torsion pendulum used in measuring total egg viscosity.

determinations, the reflection of the light was adjusted to the edge of the zero mark. When the frame was rotated, the time for the swing to decrease in amplitude between the other two marks was obtained by means of the light reflected on them. A stop watch with a tenth of a second dial was used in timing the damping. When an egg is placed in the frame, and it is started swinging, the decrease in time of swinging or in number of swings between these two marks provides a measure of the damping effect of the contents of the egg.

#### Standardization

This apparatus is a type of torsion pendulum, which is a suspended body which rotates under the torque of a twisted cord, cable, or wire.

Although the principle of the torsion pendulum is based upon definite physical laws, it was deemed desirable to check the accuracy of the equipment in order to make sure that it could be used to ascertain small differences in the viscosity of the contents of eggs. For this purpose, it was necessary that the viscosity of the contents be known in order to ascertain the effect of varying sizes or weights of eggs and to find the effect produced by variations in the width and in the length of the egg itself. Eight weight groups, representing the range within which the majority of eggs would fall, were

chosen for this part of the standardization. These eggs were all weighed to the nearest one-fourth gram on the same day in which they were laid. They were then measured with a micrometer calipers to get the maximum length and diameter. A small hole was made in the large end of the egg, and the yolk and albumen were removed by means of a pipette. The shell was thoroughly washed, and allowed to drain and dry before it was used.

A solution with a viscosity approaching that of egg albumen was preferred, and glycerol was selected. In order to cover a range of viscosities, various dilutions were made with distilled water, using volumetric measurements at 26.5 degrees C. The list of dilutions with the Saybolt reading (a standard method of expressing the viscosity of liquids) and the time to damp between two given marks when placed in the shells of two 60 gram eggs, are given in Table I.

No provision had been made to control temperature and it was necessary to make these readings when the room temperature was at 24 degrees. This introduced the possibility of an error due to fluctuations in temperature, even though the temperature was checked at the beginning and at the end of the period in which the readings were taken.

The most striking feature of this series of readings was the maximum damping effect reached at the 90 and 95 percent dilutions of glycerol. While this is to be expected, it is interesting to note the point at which the minimum time to damp,

TABLE I

Viscosity and Damping Effect of Glycerol Solutions A

Percent glycerol	Saybolt reading 24 degrees C. (Seconds)	Time to damp in egg shell 24 degrees C. (Seconds)
100	1577.1	14.7
95	707.4	13.3
90	546.7	13.3
85	293.3	14.6
80	186.0	16.8
75	134.8	18.1
70	90.8	20.5
65	67.5	23.0
60	60.4	25.4
55	51.8	27.6
50	46.6	27.8
45	42.5	30.3
40	38.5	31.4
35	37.0	35.0
30	35.4	37.2
25	33.8	38.6
20	32.5	40.8
15	32.3	43.3
10	31.5	44.5
5	31.2	46.9
H <sub>2</sub> O	30.2	48.2

or conversely, the maximum damping effect was attained. In order to further verify this information with eggs, several eggs were taken from a refrigerator at 0 degrees C., and readings were made. The mean time to damp for four eggs was 18.3 seconds. These eggs were then placed in warm water which was maintained at 40 degrees for three hours, and the readings were repeated. A mean damping time of 34.1 seconds was obtained. The eggs were then hard boiled, and a mean damping time of 57.7 seconds was obtained. This illustrates the fact that increasing the viscosity by decreasing the temperature will increase the damping effect, yet complete solidification has the opposite effect.

It was suggested that the maximum damping effect of the solutions at 90 and 95 percent glycerol might be due to the fact that water and glycerol might form a combination rather than a true solution, thus vitiating the diluting effect of the water. For this reason, another series of dilutions was made, using ethylene glycol, which is similar to glycerol in structure, as the diluent. These solutions were made by volume at 25 degrees C. Unfortunately, no Saybolt readings were made on these solutions. However, the damping effect was obtained over a wider range of egg shell sizes. Eggs weighing from 40 1/2 grams to 90 1/4 grams were used, and the shells were prepared as described above. The maximum damping effect was obtained at 65 to 75 percent glycerol, indicating that the same



effect was manifested at practically the same relative viscosity. This shows that damping effect is a function of the viscosity of the contents of the egg shell, and that the maximum damping effect obtained at a certain point in the range of viscosities used is due to the viscosity and not to a chemical combination which might exist in the system used. It is also evident that increases in viscosity produce a cumulative damping effect only within limits, and that when these limits are reached, increases in viscosity result in a decreasing effect upon the damping of the pendulum.

In this series of experiments, eggs of the same weight but of different lengths and diameters were carefully measured. Twenty-six eggs weighing 56 grams each, varying in length from 5.14 cm. to 6.14 cm., and in width from 3.74 to 4.14 cm., are used as an example. Several of these eggs were identical in one dimension, with the other varying somewhat. In each case, it was found that for shells from the same original weight of egg, the damping effect was identical, when measured in time to damp, regardless of the shape of the shell as determined by maximum length and diameter. This may be because only full swings of the pendulum can be timed and the differences in dimensions would not be sufficient to cause the damping to vary full swings, or it may be because the moment of inertia of the pendulum itself was so great as to offset the difference in damping effect caused by the relatively small differences in length and diameter.

This series of eggs showed very clearly that mass affected damping, as damping effect increased regularly with the weight of the egg.

At this point a controlled temperature cabinet was made available. It is illustrated in Fig. 2. Water pipes are provided for reducing the temperature, and the cabinet is heated by means of four 100 watt light bulbs. A double glass window is provided at the right of the torsion pendulum to allow the light to be reflected out to the wall of the room where the marks were arbitrarily placed to be used in measuring damping.

A fresh set of glycerol solutions was prepared to be used under controlled temperature. Only four dilutions were made, as these seemed to cover the range in which the majority of the fresh eggs would fall. Viscosity was measured with a Saybolt Viscosimeter, using a Furol opening at 25 degrees C. The readings given in Table II may be converted to standard Saybolt readings, since the standard Saybolt reading for distilled water was 30.8 under the same conditions.

TABLE II  
Viscosity of Glycerol Solutions C

Percent glycerol	Saybolt reading (Seconds) (Furol opening)	Damping time in seconds			
		46 grams	50 grams	56 grams	60 grams
100	252.3	30.5	29.0	25.3	24.3
90	58.7	19.1	16.5	15.1	14.0
70	14.9	20.5	18.8	16.4	15.2
50	10.4	25.3	24.0	21.4	20.2
H <sub>2</sub> O	8.1				



Fig. 2. Interior of the controlled temperature cabinet.

These solutions were used in a series of egg shells which had been prepared in the manner described above. As was the case with the ethylene glycol solutions, the damping effect was identical, within the limits of experimental error, for shells from eggs which had the same original weight, regardless of the shape as determined by maximum diameter and length. The damping time for the original weight of the eggs used is given in Table II. Since the weight for each weight class of shells varied with the solution used, the results are given for the original egg weight. The weights of the glycerol filled shells are presented in Table III.

TABLE III

Weight of Glycerol Solutions in Egg Shells

Original egg weight (Grams)	100 percent glycerol	90 percent glycerol	70 percent glycerol	50 percent glycerol
	Weight in grams	Weight in grams	Weight in grams	Weight in grams
46	54.0	52.5	51.8	50.0
50	58.5	58.0	57.0	54.8
56	66.0	65.0	64.0	62.0
60	70.7	69.0	68.4	66.4

The results obtained with these solutions again emphasized the fact that there was a point of maximum damping effect in the curve. A question naturally arose as to which side of the curves the values of the eggs might fall. That is an egg

weighing 56 grams might produce the necessary damping effect in 16 seconds, and this value might readily fall at either side of the maximum damping point of the curve. Changing the temperature would provide a solution for this problem, but this is obviously impractical if the pendulum is to be used for a large number of determinations. A more practical solution was effected by decreasing the period, obtaining a frequency which was high enough to insure that the readings were all distinctly upon the high frequency side, which is the low viscosity side. This change, together with the practice of calculating the period for the empty pendulum, for the pendulum with a bar of known moment of inertia, and also the number of swings to damp the empty pendulum between the two given marks, put the readings upon a stable physical basis. The practice of counting the number of swings instead of taking the time to damp was also adopted. This allowed for counting fractions of swings, making the readings more accurate. When all of these data are available, readings taken on any one date may be corrected for any variations in the damping effect of the pendulum itself, and may therefore be compared with readings taken on any other date. In actual practice, it has been found that the period of the pendulum, either empty or with the bar of known moment of inertia, remains the same. The number of swings required to damp the pendulum between the two given points varies slightly. This seems to be due to changes in the adjustment of the screws which hold the piano wires at either end.

### Calculation of K

The corrections for changes in damping effect of the empty pendulum have been worked out by a formula devised by Atanasoff, and given by Atanasoff and Wilcke (3). By means of this formula, a constant, K, has been calculated for a number of swings at a frequency of 1.75 swings per second. The following is the formula for K in its simplest form:

$$K = \frac{2 I \cdot .329}{P} \left( \frac{1}{N_1} - \frac{1}{N} \right) .$$

In deriving this formula, the ratio of the two angles formed between the zero mark and the other two marks, with the pendulum as the apex, was used. The numerical value, .329, is the natural logarithm of this ratio. I is the moment of inertia of the empty pendulum; P is the period of the empty pendulum; N is the number of swings to damp the empty pendulum; and  $N_1$  is the number of swings to damp the pendulum with an egg in it. In order to reduce the formula to the simple form given above, it was necessary to assume that I was equal to  $I_1$  (moment of inertia with an egg in the pendulum), and that P was equal to  $P_1$  (period with an egg in the pendulum). Actually, this is not true, but the difference is so small that it can be ignored without affecting the final results. This value of K is not adjusted for the weight of the egg. In other words, any egg which damped the pendulum in the same number of swings would have the same K value regardless of its weight. In order

to use K as a direct basis of comparison, the eggs must be of the same weight. When the eggs are not of the same weight, K must be corrected for the difference in weight, and it may then be used as a basis for comparison of the relative total viscosity of the contents of the eggs. The value for K is dependent upon the damping of the empty pendulum, and for the purpose of simplifying calculations for each egg, two curves have been plotted for the extremes of damping encountered with the empty pendulum, which were from  $N = 70$  to  $N = 90$ . These curves are presented in Fig. 3, and intermediate values may be read by interpolation.

In order to determine the relationship between the number of swings required to damp the pendulum when whole eggs were used, a series of determinations were made with fresh eggs. The mean damping effects of eggs of the various weight classes selected are presented in Table IV, together with the number of eggs used in determining each weight point.

TABLE IV  
Mean Number of Swings to Damp and K Values

Egg weight (Grams)	Number of eggs	Mean number of swings	Mean K
45	57	20.04	66.89
47	122	19.88	69.60
50	100	18.60	76.00
53	118	17.20	83.99
56	158	16.50	87.72
60	104	15.23	98.47

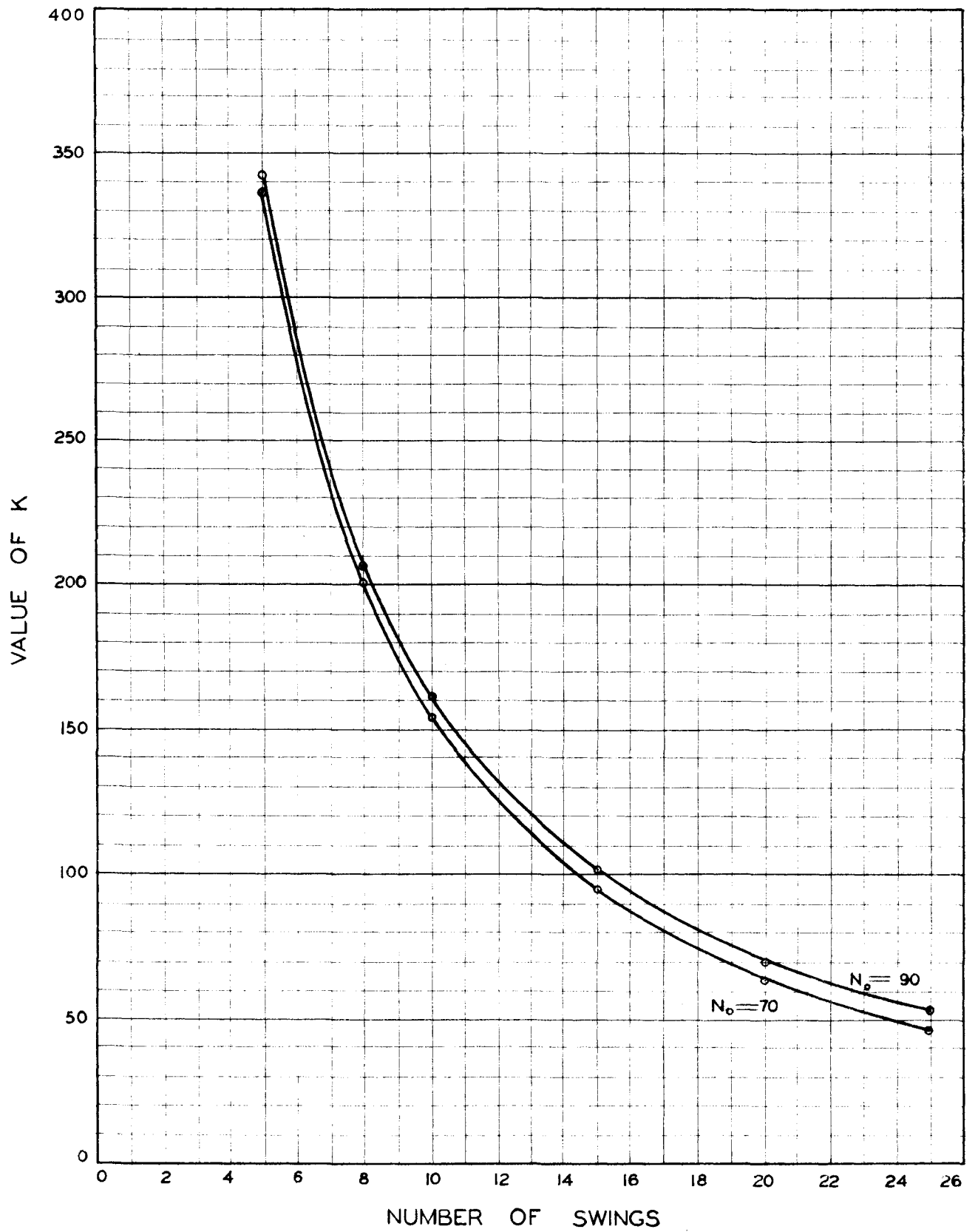


Fig. 3



It will be seen from these data that the number of swings decreases regularly with the increase in the weight of the eggs, and that K, due to the method of calculation, is inversely related to the number of swings.

#### Viscosity of Thin Albumen

It has been demonstrated that the torsion pendulum may be used to measure the viscosity of a homogeneous liquid. It has been demonstrated too that eggs differ in their damping effect when they are rotated in a torsion pendulum even though they are of equal weight. However, the contents of an egg are not homogeneous. As stated by Pearl and Curtis (10), Romanoff (13), and by Almquist and Lorenz (2), the albumen of the egg is made up of at least three separate layers. A layer of thin white is found just inside the shell membranes, then a layer of thick albumen, and another layer of thin is found within the thick. There are least three layers of albumen, and some investigators make still further distinctions. The exact number of layers of albumen is not pertinent to this problem.

The yolk is found at approximately the center of the albumen, anchored by means of the chalazae, which may or may not be considered as a part of the albumen. In order to determine whether the difference in damping effect was due to the amount, percentage, or viscosity of the thin albumen adjacent to the

shell, or whether it was due to the amount or percentage of thick albumen, determinations of the K values were made for 12 eggs of each of three different weight classes. They were then broken out, and the amount and percent of the thick and thin albumen was determined by means of a modified Ostwald pipette\* which was arbitrarily graduated so as to give a value of 2.2 seconds for distilled water at 25 degrees C. For this purpose, the direct readings were used, as it was not feasible to determine the density of each individual sample of albumen. This method was used in preference to the Doolittle Viscometer (6) because of the small amount of albumen available. The results of these determinations are presented in Table V.

These results were subjected to a statistical analysis, using the method described by Wallace and Snedecor (19) to determine the correlations between K and the percent and volume of thin albumen, volume of thick albumen, and viscosity of thin albumen, and between percent thin albumen and its viscosity, and also the multiple correlation between K and the percent and viscosity of thin albumen. These correlations were calculated for each weight group separately, and then for the total, which was obtained by pooling the three groups. The correlations are given in Table VI.

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\*This pipette was constructed by Dr. L. C. Bryner of the Chemistry Department at the request of the author.

TABLE V

Percent and Viscosity of Thin Albumen and K

Egg No.	Weight (Grams)	No. of swings	C.C. Thick	C.C. Thin	Percent thin	K	Viscosity Time in seconds
77	45.0	18.0	17.0	10.0	37.04	79.0	6.8
78	45.0	16.1	13.0	13.5	50.94	90.5	13.2
80	45.2	18.0	14.0	10.5	42.86	79.0	8.1
81	44.8	17.2	21.5	7.0	24.56	83.0	9.1
82	45.0	19.0	19.5	8.0	29.09	73.0	7.5
83	45.0	17.0	17.0	7.0	29.17	85.0	10.0
90	44.8	17.0	14.0	6.0	30.00	85.0	8.3
91	45.0	21.0	13.8	12.0	46.60	63.0	17.3
92	45.0	18.0	18.0	8.5	32.08	79.0	8.3
93	45.0	21.8	17.5	8.0	31.37	61.0	7.7
95	45.0	18.2	20.0	5.5	21.57	78.0	9.0
96	45.0	18.0	16.5	10.0	37.74	79.0	7.1
2	50.0	15.0	15.0	13.0	46.43	100.0	7.3
3	50.0	22.1	13.0	13.0	50.00	61.0	9.6
4	49.8	18.0	13.5	13.0	49.06	79.0	7.0
5	50.0	18.2	19.5	7.0	26.42	78.0	11.6
6	50.0	19.2	14.0	10.8	43.43	71.5	5.1
7	50.0	18.0	19.5	5.5	22.00	79.0	8.8
8	49.8	21.0	21.0	5.5	20.75	63.0	8.0
9	50.2	17.2	18.0	9.0	33.33	83.0	11.2
10	50.0	19.0	22.0	5.5	20.00	73.0	16.1
11	50.2	18.0	18.5	9.0	32.73	79.0	9.3
12	50.0	16.0	22.0	5.0	18.52	91.0	12.4
13	50.0	16.0	11.0	15.5	58.49	91.0	11.0
31	56.0	15.0	24.0	7.0	22.58	100.0	9.9
33	56.0	17.0	12.5	11.5	47.92	85.0	7.0
34	56.0	15.0	23.0	5.0	17.86	100.0	9.5
35	56.0	14.0	12.8	12.0	48.48	111.0	8.4
36	56.0	14.0	22.0	10.0	31.25	111.0	15.4
37	56.0	14.0	16.0	15.5	49.21	111.0	9.5
38	56.0	13.8	11.5	17.0	59.65	113.0	13.5
39	56.0	14.3	26.0	7.5	22.39	109.0	11.7
40	56.0	13.6	18.5	14.5	43.94	114.0	7.3
41	56.0	14.0	22.0	7.5	25.42	111.0	9.6
42	56.2	15.0	22.5	7.0	23.73	100.0	9.9
43	56.0	12.2	22.0	7.5	25.42	127.0	12.0

TABLE VI

Correlations Between K and Albumen Data\*

Correlations	Weight of eggs			Total
	45 grams	50 grams	56 grams	
Percent thin albumen and K r =	-.0741	.1789	.0339	.0525
Viscosity of thin albumen and K r =	.5366	-.4447	-.1386	-.0735
Volume of thin albumen and K r =				.2190
Volume of thick albumen and K r =				.2275
Percent thin albumen and viscosity r =	-.1562	.0770	.4444	.1705
Percent thin, viscosity of thin and K R =	.1566	.2501	.4547	.1825

\*None significant.

Since none of the calculated correlations equal the values necessary for significance with the appropriate degrees of freedom, the assumption seems justified that any relationship between the volume or percent of thin albumen, the viscosity of the thin albumen, or the percent thick albumen, and the value for K are merely chance relationships. This being the case, the value for K must measure a combination of all of these factors, together with an influence due to the chalazae and yolk. It seems logical that an index should measure the combined effects of the several parts, since the quality of an egg depends upon the entire contents, and not upon any one or two individual components.

#### Application of the Torsion Pendulum to Egg Quality Studies

While the data used in the standardization of the torsion pendulum were being collected, the apparatus was used to begin a study to determine whether the differences in the eggs were due to the individuality of the hen, or whether these differences were due to the rations fed the hens producing them. For this purpose, five pens of Single Comb White Leghorn hens were chosen. The birds in four of these pens were selected on the basis of their previous egg production and ancestry in such a manner as to equalize the past production records of the pens, and to divide sisters equally among the pens in so far as this was possible. These pens were made up and placed on feed

October 1, 1933, and the eggs were not used in this experiment until May 21, 1934. The same basal ration was used in all of these pens. It consisted of two parts of ground corn, one of ground oats, and one of ground wheat. The supplements to the basal ration were as follows:

TABLE VII  
Supplements Added to 100 Pounds of Basal Ration  
(Pounds)

Supplement	Pen number			
	29	31	35	36
Corn Gluten Meal	2.50			
Dried Milk		1.25		
Soy Bean Oilmeal			1.25	
Meat and Bone Meal				1.25
Bone Black	0.44	0.50	0.25	0.06
Salt	1.00	1.00	1.00	1.00
Cod Liver Oil	1.00	1.00	1.00	1.00
Bone Meal*	8.00	8.30	8.20	6.50

\*Substituted for the bone black on October 1, 1934.

This series of pens was a part of a feeding experiment which ended on October 1. For the purpose of that experiment, it was considered desirable to change the rations from low phosphorus to high phosphorus rations for the following year. This change was made in all pens at the same time, and practically the same level of phosphorus was used in all cases. For that reason, it did not interrupt the continuity of the egg quality studies.

The fifth pen was pen 45, a group of 10 inbred sisters, with a coefficient of inbreeding (Wright's) of 50 percent. These birds had not been inbred for egg quality factors, but they were used in this experiment to determine whether they were more uniform than the non-inbred birds in respect to total egg viscosity.

The ration fed this pen was:

Ground Yellow Corn	370
Ground Oats	200
Wheat Middlings	140
Meat and Bone	100
Dried Milk	80
Alfalfa Meal	70
Ground Oyster Shell	30
Salt	10
Cod Liver Oil	10

At the time this work was started, the birds were in good production, and it was not possible to handle all of the eggs from all of the pens every day of the week. For this reason, all of the eggs laid by the birds in pens 29, 31, 35, and 36 on three days of the week were taken as a representative sample, while all of the eggs from pen 45 were used daily. These eggs were placed on wire bottomed trays in the cabinet each afternoon, and the determinations of damping effect were made the following forenoon. This procedure was followed uniformly, with very few exceptions. The time allowed by Sharp and Powell (14) for the eggs to come to a uniform temperature was about three hours, but in this case at least twelve hours were allowed. Temperature is an important factor in these results, and the egg must be at a uniform temperature throughout.

All of these eggs were individually pedigreed, and the weight of each egg was recorded immediately after the damping readings were made. Weights were taken to the nearest quarter of a gram. With this information, it is possible to determine (a) the variation between the eggs of the same hen, (b) the variation between the eggs of different hens, and (c) the variation between the eggs from the hens on the different rations.

The results will be presented in two parts, the first including the results obtained from May 21 to February 1, when the period of the pendulum was changed. The second group of data was obtained from February 1 to April 16, using a higher frequency.

A separate curve for the calculation of K was developed for the eggs run during the time from May 21 to February 1. This curve is based upon the period, moment of inertia, and number of swings to damp the empty pendulum as they were measured on February 1. This curve may be found in Fig. 4. Only one curve is available for use in calculating the K value for these earlier data because the damping effect of the empty pendulum was not obtained before or after each series of determinations. Consequently, the accuracy is not as great as for the later calculations, but the period of the empty pendulum and the period with the bar of known moment of inertia have since been found to be remarkably constant for the present apparatus, and the error due to variation in the number of swings



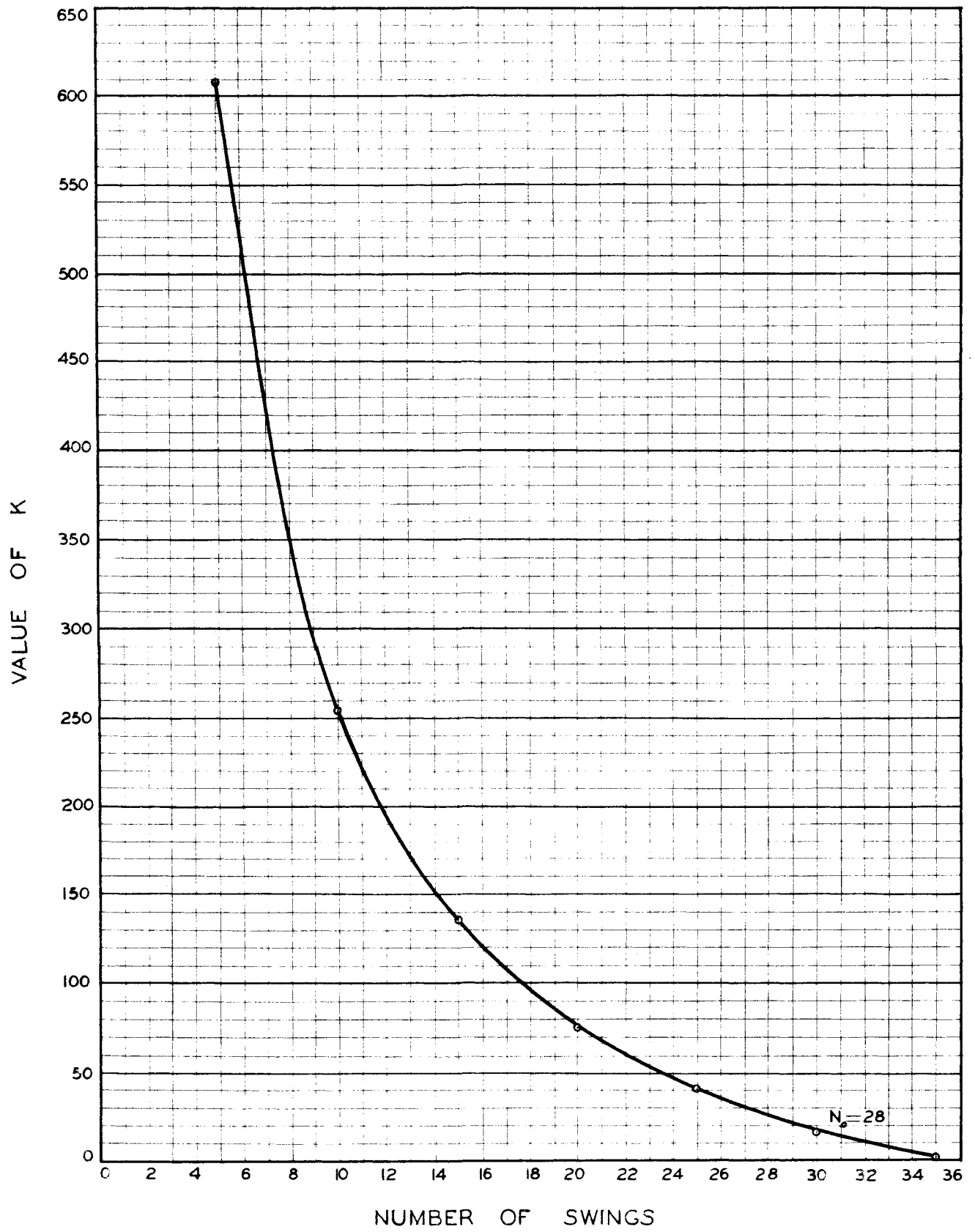


Fig. 4

to damp the empty pendulum has been comparatively small. Therefore, the results have been used to compare the eggs of the different hens, and the eggs produced by hens of different rations, but no attempt has been made to analyze the seasonal difference in the K values for the eggs.

The results were analyzed by Fisher's method of analysis of variance and covariance as described by Snedecor (15). Since this method involves the use of correlations, it is necessary to use the logarithms of K instead of the actual values in order to establish a linear relationship between weight and K. This was justified when the relationship between weight and K was not altered by the application of logarithms to the data in Table IV.

The data for each pen were analyzed separately in order to determine whether the variations in the total relative viscosity of the eggs produced by the various hens differed significantly. Since there were only a few birds in pen 45, this pen will be used as an example of the data obtained.

TABLE VIII

Pen 45

Hen No.	Number of eggs	Mean egg weight	Mean log K
D 20	38	58.46	1.70
52	60	53.05	1.47
53	13	54.54	1.65
105	76	57.57	1.78
112	56	53.30	1.57
114	88	55.80	1.66
115	77	54.79	1.57
155	32	52.18	1.87
162	74	53.50	1.47
263	13	48.98	1.66

### Statistical Analysis of the Data

It has been shown that the weight of the egg influences the K value for that egg. By means of analysis of variance, it was found that there was a highly significant difference between the weights of the eggs produced by the individual hens in this pen. This simply means that the variations in the weights of the eggs produced by different hens are greater than those of the eggs produced by the same hen. This is to be expected in any group of birds which have not been selected for uniformity in respect to egg weight.

This analysis also showed that there was a highly significant difference between the K values for the different hens. Before arriving at a conclusion concerning K, the effect of egg weight must be removed, since the hens differed in egg weight. This was accomplished by the use of analysis of covariance. In this procedure, the correlations between weight and K were calculated for the eggs from the same hen, for the eggs produced by the different hens, and for the total which combines all of the eggs from all of the hens.

In this pen, a correlation of  $r = .4197$  is found with 517 degrees of freedom for the between the eggs from each hen. This is highly significant. The correlation for weight and K between the eggs from the different hens is slightly larger, being  $.4971$ , but with only 9 degrees of freedom it is not significant.

However, since this correlation is as large as that between the eggs from the same hen, there is no reason to suppose that the weight and K are not related between hens. A greater number of hens might make this a significant or highly significant correlation, indicating that the effect of weight on the K value between hens is not due to chance. For the total,  $r = .4444$ , which is highly significant. These correlations may be taken as proof for the fact that weight and K tend to be associated together, but they are not proof that K is a characteristic of the hen.

Since the weight of the egg affects its K value, it is necessary to prove that weight and K are two distinct measurements. It is apparent that both weight and K are significantly different between hens, but the amount of K which is due to weight is not evident. By analysis of covariance, the effect of weight on K was removed, and the result was an adjusted mean square for K which may be considered as the best estimate of K when all of the known sources of variation have been removed.

Using the adjusted mean square of K for the between eggs from the same hen as experimental error, a highly significant difference is found for the K value of eggs produced by different hens. This is proof for the conclusion that the K value of an egg differs significantly from hen to hen after proper corrections have been made for differences in mean egg weight.

The remaining four pens were treated in a similar manner, and the results obtained were essentially the same, although there were some variations in the correlations. The results have been summarized in Table IX. The data for pen 45 have been included in this table for the purpose of comparison.

From Table IX, it may readily be seen that the hens within each pen differed significantly in mean egg weight, but the variation in egg weight for the eggs from the individual hens is no greater for the non-inbreds than it is for the inbred hens. This is shown by the variance (mean squares) for the between eggs from the same hen.

The correlations between weight and K differ somewhat in magnitude from pen to pen. A study of these correlations suggests several possibilities. If the total viscosity of the eggs, as measured by K, is a characteristic of the hen which produces that egg, we would expect to find a highly significant positive correlation between the weight and K of the eggs produced by any one hen, providing neither remains constant. Further, if such were the case, we might or might not find a highly significant correlation between the weights and K's of the eggs produced by different hens, because the effect of the weight on K might be masked, to some extent at least, by the individuality of the various hens. If no correlation is found between the hens, it would mean that the differences in K of the individual hens were great enough to mask the effect of the

TABLE IX

Correlations and Analysis of Variance and Covariance of  
Pens 29, 31, 35, 36 and 45

Pen No.	Source of variation	Mean square			Correlation W and K	Log K	
		D/F	Weight	Log K		D/F	Adjusted mean square
29	Total	503			.2311**		
	Between hens	19	280.7821**	.3791**	.4486*	18	.3196**
	Between eggs from the same hen	484	11.2736	.0379	.1056*	483	.0376
31	Total	490			.5653**		
	Between hens	24	624.2504**	.9582**	.6757**	23	.5434**
	Between eggs from the same hen	466	14.1896	.0399	.3969**	465	.0337
35	Total	601			.4206**		
	Between hens	24	312.5788**	.6114**	.6191**	23	.3934**
	Between eggs from the same hen	577	11.3463	.0364	.2490**	576	.0342
36	Total	472			.4719**		
	Between hens	18	230.9539**	.6182**	.7009**	17	.3330**
	Between eggs from the same hen	454	9.5017	.0342	.2837**	453	.0315
45	Total	526			.4444**		
	Between hens	9	280.7011**	.8476**	.4971	8	.7180**
	Between eggs from the same hen	517	11.2691	.0270	.4197**	516	.0223

egg weight on K or that one was practically constant. If the opposite condition exists, that is, if a significant or highly significant correlation is found for weight and K between hens, it would mean that the differences in the individuality of the hens for this factor are relatively small, and that they do not overcome the effect of egg weight. One would also expect to find a highly significant correlation between weight and K for the total, which includes both between hens and between the eggs from the same hen, for it has already been shown that, when the means of a large group of eggs produced by many different hens are used, the K increases as the weight increases. The same explanation would apply for the total as for between, that the existence of a correlation depends upon the degree of variation between hens for the value of K.

If the hypothesis is correct that a correlation between hens indicates that the differences for K are small, or, in other words, that the characteristic of producing eggs with a consistent K value is less firmly fixed in the individual, then these correlations would indicate that the difference between the hens is much more deeply fixed in the inbred than it is in the non-inbred birds. They also indicate that K is a much more clearly defined characteristic in the inbred birds.

The point is further substantiated by a study of the mean squares between the eggs from the same hen. It will be noted that the mean square for weight is of the same magnitude for pen 45 as for the non-inbred hens, but that the variance for K

is smaller. The difference that exists between pen 45 and the other four pens is of particular note because of the uniform variability in egg weight from pen to pen. The fact that there is as much variability in egg weight among the inbreds, but that there is less variability in the K value for the eggs produced by the individual hens, further supports the observation that these birds are producing eggs which are more uniform in respect to total egg viscosity.

The data obtained since the adjustments were made to increase the accuracy of the determination of K were analyzed separately, but the same method of analysis was used throughout. These results are denoted by means of "B" following the pen number. Here again, the results were substantially the same, and they are therefore grouped in Table X.

It is apparent that the birds vary in mean egg weight, just as they did in the first analysis. However, the correlations between weight and K show that weight and K are not as closely associated in pens 29B, 35B and 45B as they were in the first analysis. No explanation can be offered for this difference. It is certainly not due to the changes which have been made in the apparatus, for changing the period of the pendulum will not change the relationship between weight and K.

These results also show that K is a characteristic of the individual hen, with the least variability in K occurring in the eggs from the pen of inbred birds, as before.



TABLE X

Correlations and Analysis of Variance and Covariance  
for Pens 29B, 31B, 35B, 36B and 45B

Pen No.	Source of variation	Mean square			Correlation W and K	Log K	
		D/F	Weight	Log K		D/F	Adjusted mean square
29B	Total	197			.1648		
	Between hens	12	69.8150**	.0701**	.1818	11	.0740**
	Between eggs from the same hen	95	6.8784	.0213	.1635	94	.0210
31B	Total	123			.4163**		
	Between hens	13	151.3931**	.0967**	.6054*	12	.0663**
	Between eggs from the same hen	110	9.8566	.0237	.2840**	109	.0220
35B	Total	116			.2659**		
	Between hens	12	108.1350**	.1526**	.3702	11	.1437**
	Between eggs from the same hen	104	6.4404	.0052	.0060	103	.0052
36B	Total	115			.4736**		
	Between hens	12	129.9725**	.1374**	.4673	11	.1171**
	Between eggs from the same hen	103	7.9202	.0032	.5355**	102	.0023
45B	Total	201			.0382		
	Between hens	7	69.9442**	.0562**	.3320	6	.0584**
	Between eggs from the same hen	194	8.9665	.0021	-.1130	193	.0021

With these points established, a comparison was made of the four pens, keeping the data in two separate groups as before. Pen 45 was not included in this comparison because of the difference in the manner of selecting the birds.

The summary of the data for the several pens is given in Table XI.

TABLE XI  
Summary of the Five Pens

Pen No.	Number of hens	Number eggs per pen	Weight	Log K
29	20	485	50.78	1.64
31	25	467	49.76	1.69
35	25	578	50.48	1.65
36	19	454	50.69	1.64
45	10	518	54.64	1.62
29B	13	96	53.89	1.93
31B	14	111	50.83	1.94
35B	13	105	53.12	1.98
36B	13	104	53.66	1.94
45B	8	195	59.49	1.96

The birds in pen 45 produced larger eggs than the remaining four groups, but the value for K is very similar.

The data for the individual pens were combined in analysis of variance and covariance to find whether the ration fed the hens was affecting the K value of the eggs produced. Although pen 45 received a ration which differed from that of the other four pens, the data for this pen were not included because of

the difference in the breeding of the birds. The results of this analysis are presented in Table XII.

TABLE XII  
Analysis of Variance and Covariance for Pen Differences  
Pens 29, 31, 35 and 36

Pen No.	Source of variation	Mean Squares			Log K	
		D/F	Weight	Log K	D/F	Adjusted mean square
A	Between pens	3	105.177	.2738	2	.0173
	Between hens					
	within pens	85	376.187**	.6588	84	.4229**
	Between eggs from the same hen	1981	11.575	.0371	1980	.0346
B	Between pens	3	236.027	.0522	2	.0781
	Between hens					
	within pens	49	115.574**	.1138	48	.0945**
	Between eggs from the same hen	412	7.8234	.0133	411	.0127

These results indicate that any difference in egg size between the pens is certainly due to chance. In the process of selecting the hens, the pens have evidently been very well balanced as to egg size. The variance of K also shows that the ration is not affecting the K value of the eggs produced.

The primary purpose of this analysis was to determine whether the ration influenced the two variables studied, but the data obtained offer more complete proof of the conclusion that K is a characteristic of the individual hen. In testing

the differences between the pens, the variance for between hens was used as experimental error. The analysis may be carried further, however, and the between hen differences may be tested using the variance between eggs from the same hen as experimental error. When this is done, a highly significant difference is found between hens for both weight and K. This is stronger evidence of the fact that K is a characteristic of the individual hen because of the increased size of the group resulting from pooling the data from the four pens.

#### SUMMARY

A new method which involves the use of a torsion pendulum has been developed for use in egg quality studies. This method provides a measure of the total viscosity of the egg, i.e., the combined viscosity of all of the components of the interior of the egg. This method eliminates, to a large degree, the human element which influences candling, and it is much more rapid than those methods which require breaking out and measurements of the contents. This method does not supplant candling, but merely supplements it.

It has been shown that the weight and K value for eggs are closely associated. Charts for the conversion of number of swings to K values have been prepared for various rates of damping of the pendulum itself.

This method has been used in studying the effect of the individuality of the hen and of the ration upon the K value of the eggs produced by the hen. It has been found that the K value is not influenced by the rations used, but that it is a characteristic of the hen. The rations used consisted of a basal ration of grains with protein supplements of dried milk, meat and bone meal, soy bean oilmeal, and corn gluten meal.

A group of inbred sisters were included in this study. The K values of the eggs from these birds were less variable

than those of the non-inbred birds, but there was a distinct difference in the K values of eggs produced by the inbred sisters, after weight differences had been accounted for.

### CONCLUSIONS

1. The torsion pendulum may be used to obtain an index of the interior quality of an egg.
2. The index, K, is a measure of the combined viscosity of the entire contents of the egg, and not of any one individual component.
3. The weight influences the K value of the egg. K increases with the weight.
4. The rations used did not affect the K values of the eggs produced by the hens on that ration.
5. The index obtained, K, is a characteristic of the individual hen.

LITERATURE CITED

- (1) Almquist, H. J. Relation of the candling appearance of eggs to their quality. Cal. Agr. Exp. Sta. Bul. 561. 1933.
- (2) Almquist, H. J. and F. W. Lorenz. The solids content of egg white. Poul. Sci., 12:83-89. 1933.
- (3) Atanasoff, J. V. and R. L. Wilcke. Unpublished data. Iowa State College. 1935.
- (4) Canham, A. S. Watery whites of eggs. Reports of preliminary investigations. Onderspoort Jour. Vet. Sci. and An. Ind., 1:529-566. 1933.
- (5) Cortese, D. Sulla viscosità dell'albume delle uova e sulle variazioni che essa presenta nelle uova fresche e conservate. Ann. Chim. Applicata, 19:260-265. 1929.
- (6) Doolittle, O. S. The torsion viscosimeter. Jour. Amer. Chem. Soc., 15:173-177. 1893.
- (7) Holst, W. F. and H. J. Almquist. Measurement of deterioration in the stored hen's egg. Hilgardia, 6:49-60. 1931.
- (8) Knox, C. W. and A. B. Godfrey. Variability of thick albumen in fresh-laid eggs. Poul. Sci., 13:18-22. 1934.
- (9) Lorenz, F. W., L. W. Taylor, and H. J. Almquist. Firmness of albumen as an inherited characteristic. Poul. Sci., 13:14-17. 1934.
- (10) Pearl, R. and M. R. Curtis. Studies on the physiology of reproduction in the domestic fowl. Jour. Exp. Zool., 12:99-152. 1912.
- (11) Pennington, M. E., M. J. True, A. D. Rich, and A. A. Kiess. Yolk index and thick white graded by candling for interior quality. U. S. Egg and Poultry Mag., 40:45, 48, 52. May 1934.



- (12) Perry, F. D. Influence of rations and storage on the physical characteristics of eggs. Unpublished Thesis. Library, Iowa State College, Ames, Iowa. 1934.
- (13) Romanoff, A. L. Dry matter in different layers of egg albumen. Science, 70:314. 1929.
- (14) Sharp, P. F. and C. K. Powell. Decrease in interior quality of hen's eggs during storage as indicated by the yolk. Ind. Eng. Chem., 22:908-910. 1930.
- (15) Snedecor, G. W. Calculation and interpretation of analysis of variance and covariance. Collegiate Press, Inc., Ames, Iowa. 1934.
- (16) St. John, J. L., and E. L. Green. The colloidal structure of egg white as indicated by plasticity measurements. Jour. Rheol., 1:484-505. 1930.
- (17) U. S. Dept. of Agr., Bur. of Agr. Econ., Div. of Crop and Livestock Estimates. Poultry Estimates. Washington, D. C. April 1, 1935.
- (18) Van Wagenen, A. and H. S. Wilgus, Jr. Observations on the relation of the percentages of the different layers of egg albumen. U. S. Egg and Poultry Mag., 40:37, 62. June 1934.
- (19) Wallace, H. A. and G. W. Snedecor. Correlation and machine calculation. Iowa State College, Ames, Iowa. 1931.

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